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TECHNICAL REPORT ECOM-00032-3

INVESTIGATION OF THE QUANTITATIVE DETERMINATION OF POINT AND AREAL PRECIPITATION BY RADAR ECHO MEASUREMENTS

INTERIM REPORT No. 3

By
E. A. Mueller - A. L. Sims

June 1966

ECOM

UNITED STATES ARMY ELECTRONICS COMMAND · FORT MONMOUTH, N.J.

Contract DA-28-043 AMC-00032(E)
ILLINOIS STATE WATER SURVEY
at the
University of Illinois
Urbana, Illinois

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ABSTRACT

The results of the drop size sample study indicate that volumes of about 50 m^3 are necessary to estimate rainfall rate and radar reflectivity to 10 percent accuracy with 95 percent confidence. One-cubic-meter samples are sufficiently large that rainfall rate-radar reflectivity relationships can be reliably determined. The sample size variances contribute about 10 percent of the logarithmic scatter around the regression line.

Analysis of drop size data from Indonesia yielded a reflectivity rate relationship similar to that from Miami, Florida data but with less scatter. Five-minute rainfall rate frequencies from Indonesia were also similar to those from Florida.

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SAMPLE SIZE

In order to better assess the accuracy of radar-rainfall relationships, a study of effects of sample size in the drop size distribution was initiated. Two objectives of this study were to determine the size of volume necessary to adequately describe the drop size distribution and to determine the uncertainty inherent in all previous drop size data which was collected using one cubic meter samples. Addressing the latter problem first, if a measure of the variance of the rainfall rate and radar reflectivity for a one-cubic-meter sample can be determined and if the scatter of points around the regression line of reflectivity of rainfall rate is normally distributed, a technique exists for removing the scatter due to sample size. The remaining scatter then becomes an estimate of the best accuracy in a radar measurement of rainfall rate. This portion of the problem has been solved subject to the assumption of normally distributed scatter of the points around the regression.

The size of the volume necessary to be sampled for a meaningful drop size distribution varies with the criteria for an adequate sample. The rainfall rate and radar reflectivity calculated from the drop size distribution have been used to characterize a distribution. The size of volume necessary to sample a distribution so that the calculated rate and reflectivity are obtained to a specified accuracy has been determined.

Data Collection

To provide the data for this study two raindrop cameras were operated in close proximity and at as rapid a rate as possible. In this way there was some assurance that the same parent population of drop size spectra was being sampled. Each picture or frame represents nearly 1/7 cubic meter of space. The images of drops on each frame were measured and a distribution obtained for each 1/7 cubic meter. From this spectrum, the rainfall rate and radar reflectivity were calculated. The spectrum can be characterized by these two variables and if the accuracy of the reflectivity-rate relationship is of prime importance, the accuracy of these statistics is sufficient. There were 8 m^3 of sample volume obtained for each minute. The cameras were operated during the summer of 1964 and 1965 on the East Central Illinois raingage network.

Preliminary Data Processing

Eight minutes of data from the two cameras were grouped together to produce 448 individual 1/7 m^3 samples or 64 m^3 in all. There were 17 such groups. Considerably more data was collected but the restrictions of a group to an 8-minute sequence reduced the number of useable groups to 17.

The analysis was performed with and without a logarithmic conversion. Logarithmic conversion is desirable when interpreting the results on a logarithmic regression of R on Z. The natural numbers were used to compare the effects of the transformation and to estimate the volume necessary for accurate R and Z values.

This volume is related to the natural variability of raindrops in space.

During any eight-minute period, there is a high probability that there will be rainfall rate changes. This increases the variance of the sample and is not attributable to sample size. Therefore, the effects of time varying rate should be compensated. A number of methods were investigated and finally the choice was to treat each minute of data from each camera individually. If the variable of interest is denoted by X, a regression of X on time and a mean X for the 28 points were obtained.

Let $X_R = \alpha + \beta t$

and $\overline{X} = \frac{1}{28} \sum X_i$

be the regression line and the mean obtained. Provided that the logarithmic transformation was not used, a transformation of the individual values X_i to new values of Y_i was performed according to

$$Y_i = 1 + \frac{X_i - (\alpha + \beta t_i)}{\overline{X}}$$

Thus, the variables Y_i represent the deviations of the individual measurements from the time regression line measured in units of the mean. The value of 1 was added to the expression to adjust the mean of Y to one. It does not effect the variance of Y. Initially, a group of variables which did not exhibit high time correlation were to be transformed by changing units to units of the mean of the sample. This would produce a mean of the transformed sample of one. To make the two transformations compatible,

one is added to the time trend corrected transformation. After processing some data it was noted that if the time correlation was low the same results were obtained by both transformation schemes. Since the decision as to when the time correlation is significant is an arbitrary one, the data was all processed using the time regression method. In order to assess the value of the removal of time from the variance of one-frame samples, the storm of July 25, 1964 was analyzed separately. There were 14 minutes in which the rainfall rate had a time correlation coefficient less than 0.3. The average variance for this group was 0.1372 with individual values of variance running between 0.079 and 0.205. There were 10 points for which time trend correction was made. The average variance was reduced from 0.189 to 0.146 by the time trend removal. The range of variances for the non-corrected group was 0.091 to 0.319 and for the corrected group 0.079 to 0.210. It does not appear that removing the time variance is adversely affecting the residual variances. Periods in which no trend could be noted were still less variable than the time trend removed period.

It was noted in Interim Report No. 2, that the variance when measured in units of the mean are essentially constant with respect to rainfall rate. This is to say that the chance of estimating a 1.0 mm/hr rate as 1.4 mm/hr are the same as estimating a 100 mm/hr rate as 140 mm/hr. Since the logarithmic difference between these numbers is also constant, it is not necessary or desirable to measure logarithmic deviations in units of the mean. The transformation on all logarithmic variables was

$$Y_i = X_i - (\alpha + \beta t_i)$$

After these transformations had been made on the individual one minute samples, a group of eight minutes' data from both cameras were combined to produce a 448 row observational matrix.

Since both the rate and reflectivity are linear combinations of the drop size spectra, one may average the rainfall rates of two samples instead of averaging the distribution and recalculating a new rainfall rate. Thus, to determine the results of a sample volume of 2/7 m^3, a new data matrix can be formed. The terms of the new matrix are related to the original matrix by

$$b_n = \frac{a_n + a_{n+224}}{2} \qquad \text{for } n = 1,2,3,\cdots,224$$

This procedure mixes the sample considerably as the two portions a_n and a_{n+224} do not arise from the same minute or even necessarily the same camera. A combination scheme where

$$b_n = \frac{a_{2n} + a_{2n-1}}{2} \qquad \text{for } n = 1,2,3,\cdots,224$$

was also investigated. The latter combination does not change the variances of the 2/7 m^3 sample significantly. The former technique was more easily programmed for larger combinations and was used throughout.

To achieve the larger sampling volumes, combinations of the 1-frame samples were made using

$$b_n = \frac{1}{N} \sum_{i=n}^{n+N-1} a_{[i+(i-n)(\frac{448}{N})]}$$

where $N = 2,4,7,14,28,56$

and $n = 1,2,3,\cdots,\frac{448}{N}$

As was pointed out in Interim Report No. 2, when the volume is larger than 4/7 m^3 the observational points tend to distribute normally.

Results for Size of Sample

Figure 1 is the result of this analysis for the 17 groups of data and with rainfall rate as the statistic of interest. The two extreme curves are plotted on this figure along with one-half of the remaining groups. As expected the sample variance reduces as the sample volume increases. The decrease follows approximately an inverse law. Since the populations tend to normality for sample volumes larger than 0.5 m^3, this result is to be expected. The average variance of the one-cubic-meter sample is 0.137. This can be interpreted that a spectrum determined from a 1 m^3 sample will estimate the rainfall rate to within $\pm$ 70 percent of the mean value, 90 percent of the time. It should be noted that the minimum variance curve on Figure 1 happened to be the first storm analyzed and was reported on in the previous interim report. The values reported in that report must be considered as over optimistic when the remainder of the data is considered.

Since the variances decrease inversely as the volume sampled, the average variance for any sample greater than 8 m^3 can be estimated by

$$\mathrm{var}\, R = \frac{0.096}{V}$$

where V is the volume sampled in m^3. To obtain an estimate of the rainfall rate which would be within $\pm$ 10 percent of the "true" value 95 percent of the time, would require a sample of 43.6 m^3. A volume of this size is certainly difficult to sample using known drop sizing techniques but the radar samples a much larger volume easily.

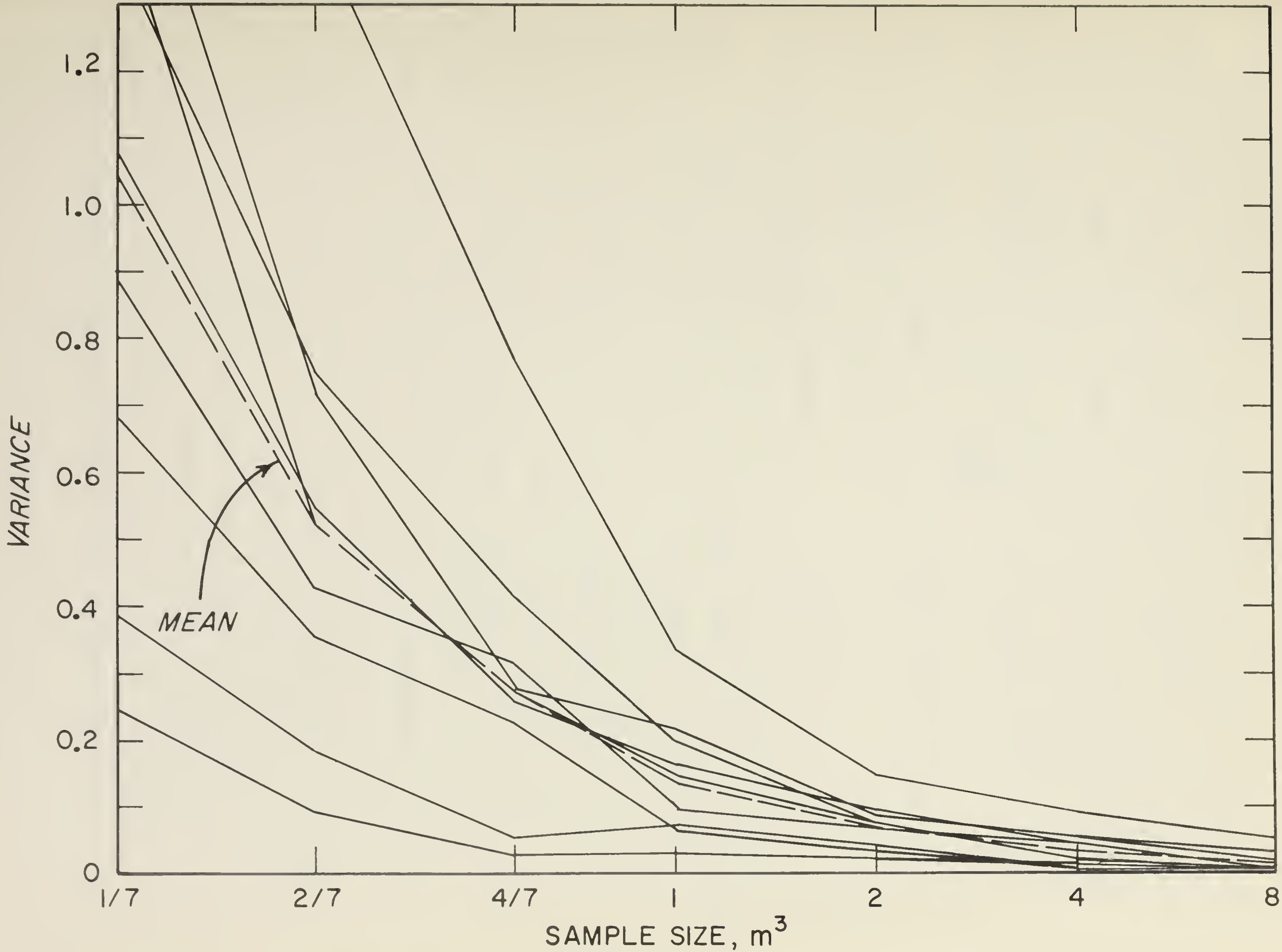


Figure 1. Variance of Rainfall Rate with Sample Size

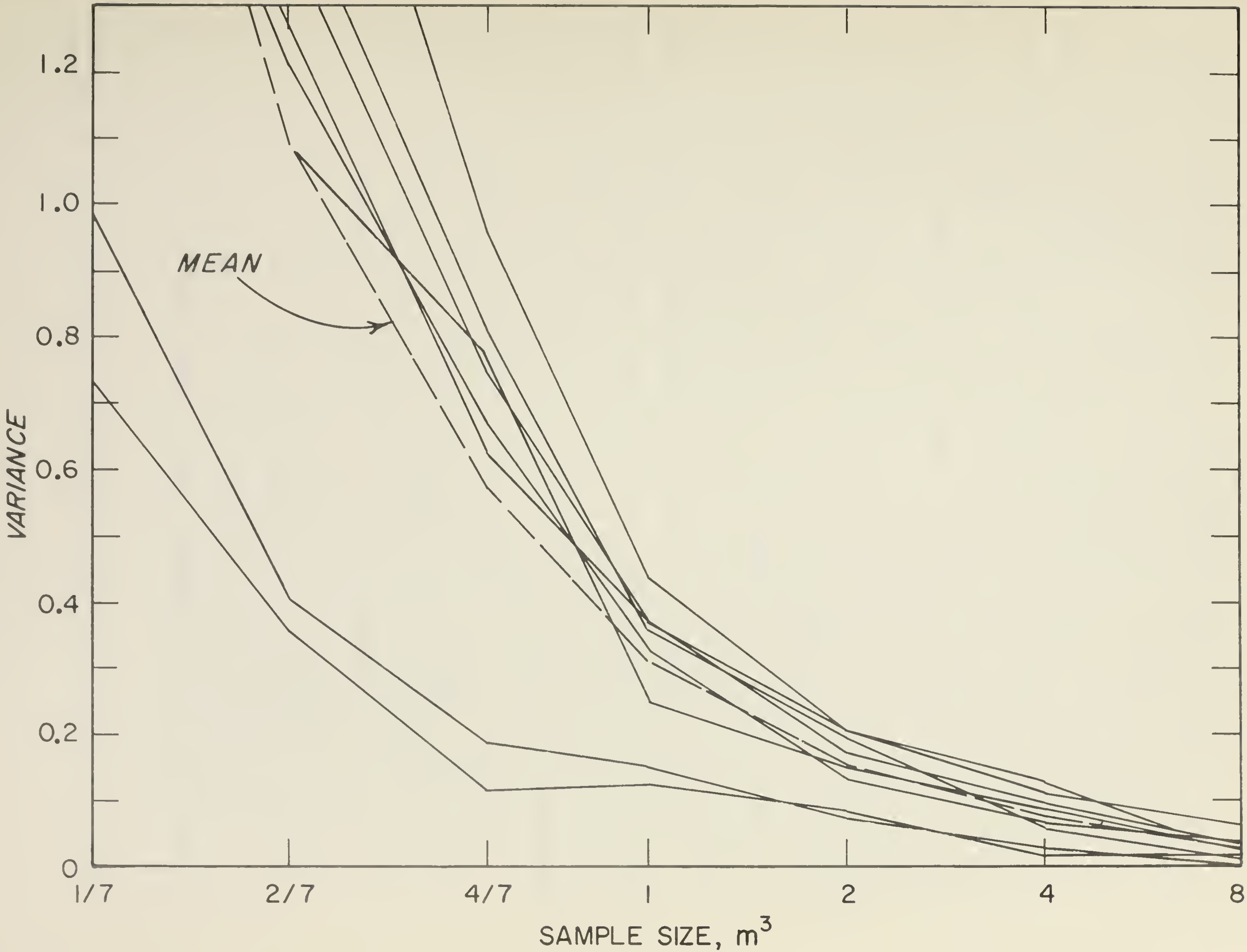
Similar results have been obtained for the radar reflectivity. Figure 2 shows the same groups as plotted in Figure 1. The total variance for any particular sample size is always greater for the reflectivity than for the rate. This is due to the higher sensitivity of the reflectivity to sampling error. The equation relating the variance of reflectivity, Z, to sample size is

$$\mathrm{var}\, Z = \frac{0.192}{V}$$

Thus, to attain the same level of confidence twice as large a volume is necessary to estimate Z.

Reduction of Regression Variances

The most important aspect of this study was to assess the effects of sample size error on the probable error of the reflectivity-rate relationship. The errors in the measurement of individual R-Z data points can be attributed to a number of causes. Some of these are sample volume error, optical error such as poor focus or drops drifting too far into tunnels, measuring error, and error due to changing meteorological conditions. Due to the observable large changes in drop size distributions, it had been assumed that of these errors the error due to inadequate sample volume would be large compared to the other errors. As the calculations proceeded the size of variances obtained from the sample size data tended to support this hypothesis when only one variable was considered. It was noted that the R and Z errors were not in fact independent and more powerful statistical techniques were needed to evaluate the results. A brief review of the methods are presented and for a more detailed and complete exposition the


MEAN
VARIANCE
1.2
1.0
0.8
0.6
0.4
0.2
0
1/7
2/7
4/7
1
2
4
8
SAMPLE SIZE, m³

reader is referred to Acton.* The method used is similar in nature to that which Acton calls "The 99.44 Percent Pure Extractor."

The problem becomes one of estimating in a large sample how much of the variance around the regression line is likely to be contributed by the probable error in the measurements of R' and Z'. The primes denote common logarithms of the variables. The logarithmic transformation permits straight line approximation of the regression line. The scatter of points after the logarithmic transformation appear to be equal for all values of the independent variable Z'. This property, called homoscedasticity, is necessary for this method to be reliable. Unfortunately there are few if any critical tests for this property and in this case none have been performed. Examination of plotted R' -Z' graphs and the qualitative observation that the scatter does not vary with Z' has been performed. Another assumption necessary for the proper application of this theory is that the scatter around the regression line is normally distributed. This assumption can be replaced by at least two others which will affect the results. The alternative assumptions which can be handled with present theory are that if sufficiently accurate R' - Z' measurements had been made, (1) the points would all be on a line or (2) the points would lie on a quadratic line. The first assumption is obviously incorrect. For if this were so, all of the scatter of points would have to be ascribed to measurement error. Then estimates of the measurement

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*Acton, F. S., Analysis of Straight Line Data, John Wiley & Sons, New York 1959

error by the results of an R' - Z' regression and from the changing volume should be equal. Since this is not true, this assumption has been discarded. The second assumption, namely the quadratic underlying assumption, may in some cases of drop size data be realistic. Usually, however, there is very little data to support any bending of the R' - Z' line. Unfortunately the scatter of points around the R' - Z' line do not distribute strictly normally. With a sample from a data location, such as Miami, with 2400 data points the distribution is not normal. This is indicative that nature produces the same rainfall rate using a variety of distributions and there is not a tendency for one type to predominate. Despite the inadequacy of this assumption, it is invoked for this study.

The statistical measure of the scatter of points around the regression is the standard error. The square of this term is the variance of the deviations around the regression line. For example this variance ranged from 0.0161 to 0.0353 for the Miami drop size data when synoptic sorting was performed. The non-stratified data had a variance of 0.0392. One may be tempted to examine the variance of R' for the one cubic meter sample and expect that this variance can be substracted from the variance around the regression line to leave the unexplained variance. The average variance of R' for one cubic meter sample is 0.0612. This would result in a negative variance of considerable size. The difficulty that is made obvious by this excercise is that the sampling error of R' is correlated with the sampling error of Z'.

Since both of these parameters have been computed from the drop size distribution, it is not surprising that such correlation exists. Qualitatively, the correlation of errors of R' and Z' tend to be such that if a line is passed through the subgroup of R' and Z' points from the sample size, the line would be nearly parallel to the R' and Z' regression line. In other words a part of sampling error is not reflected in scatter around the regression line. To determine the amount of the error variance which contributed to the scatter, the following technique may be used. This technique consists of variable transformation by axis rotation such that the error variances are no longer correlated. At the same time the regression line must be transformed and the variances around the new line determined.

A variable transformation of the following form is applied to the data:

$$v = y - b_o x$$
$$u = y - (\rho + b_o)x$$

where b_o is the regression coefficient of the data

and $$\rho = \frac{b_o^2 - 2r\frac{S_\eta}{S_\xi}b_o - \left(\frac{S_\eta}{S_\xi}\right)^2}{r\frac{S_\eta}{S_\xi} - b_o}$$

where r = correlation coefficient of errors in R' and Z'

S_η = the error variance of Z'

S_ξ = the error variance of R'

In the transformed u and v variables the error terms are uncorrelated and an estimate of the relative importance of the error variance can be made. Table 1 shows the results of this analysis for a number of locations and separations.

TABLE 1

COMPARISONS OF VARIANCES OF R' - Z' REGRESSION
AND VARIANCES ATTRIBUTABLE TO SAMPLE SIZE

Data Location	Logarithmic Regression Variance	Transformed Sample Size Variance	Percentage of Regression Variance Explained by Sample Size	Corrected Standard Error of Estimate	90% Confidence Limits from Mean Rate in Percent	
Florida	0.0392	0.00277	7	0.191	51	106
Marshall Islands	0.0289	0.00442	15	0.156	45	80
Oregon	0.0185	0.00216	12	0.128	39	62
Indonesia	0.0216	0.00267	12	0.138	41	69
Alaska	0.0202	0.00209	10	0.135	40	67
N. Carolina	0.0292	0.00306	10	0.162	46	85
Florida						
Continuous	0.0350	0.00421	12	0.175	49	94
Showers	0.0342	0.00234	7	0.178	49	96
Thunderstorms	0.0361	0.00217	6	0.184	50	101
Oregon						
Continuous	0.0177	0.00214	12	0.125	38	60
Showers	0.0182	0.00218	12	0.127	38	62
Thunderstorms	0.0079	0.00215	27	0.076	25	33
Marshall Islands						
Continuous	0.0339	0.00244	7	0.177	49	95
Showers	0.0199	0.00287	14	0.130	39	64
		Average	11.6		43	73

Examination will reveal that the contribution to the total variance by the variance of the sample size is small. In general, only about 10 percent of the total variance can be attributed to sample size when a one-cubic-meter sample of drops was obtained. In one sense this is encouraging in that the samples that have been obtained appear to be quite adequate in terms of the volume sampled to determine realistic estimations of the R' - Z' relationship. On the other hand the magnitude of the remaining variances is larger than might be desired for reliable estimation of rainfall rate from a radar. The last two columns show the 90 percent confidence limits of the estimated limits of accuracy of the rainfall rate measurement from a single reflectivity measurement with the radar. Although these limits as calculated appear to be non-symmetric, they are symmetric after the logarithmic transformation. Thus, the error in a single radar measurement will be confined to within 43 percent low to 73 percent high 90 percent of the time. These limits appear quite large, but about the same size that has been frequently observed with a radar set. Since the scatter does appear to be quite random, the total storm amount predicted by a radar may well be much more accurate as averaging of this random error would take place. However, since the scatter appears more symmetric after logarithmic transformation, there will be some bias in the time integrated rates or amounts.

ANALYSIS OF BOGOR, INDONESIA DATA

All of the Indonesia drop size data were used in a calculation of an R-Z relationship which may be useful in other similar areas

in Southeast Asia. No stratification of this data has been attempted. The overall relationship was found to be

$$Z = 311 R^{1.44}$$

using a logarithmic least squares fit with Z as the independent variable. This is quite similar to the "all data" relationship for Miami, Florida, which was found to be $Z = 286 R^{1.43}$. Figure 3 shows the R-Z points from the Indonesia data. The scatter of points is somewhat less than the scatter of points for Miami even though the relationship is similar. The standard error of estimate is 0.147 for Indonesia and 0.198 for Miami.

The raingage data obtained in Indonesia while the drop camera was there have been analyzed for frequency of 5-minute amounts. A frequency distribution of rates calculated from the 5-minute amounts is plotted in Figure 4. A total of 135 hours of rain of rates equal to or greater than 0.12 inches per hour is included in the frequency distribution. These data were obtained during a period of approximately 17 months from 31 October 1959 through 11 April 1961. A small amount of data was missed during this period, due to gage malfunctions and other reasons.

ANALYSIS OF NEW JERSEY AND NORTH CAROLINA DATA

The data from New Jersey and North Carolina have been carefully edited. Some dates and times have been found to be in error as indicated by the logs and raingage traces; these errors have been corrected.

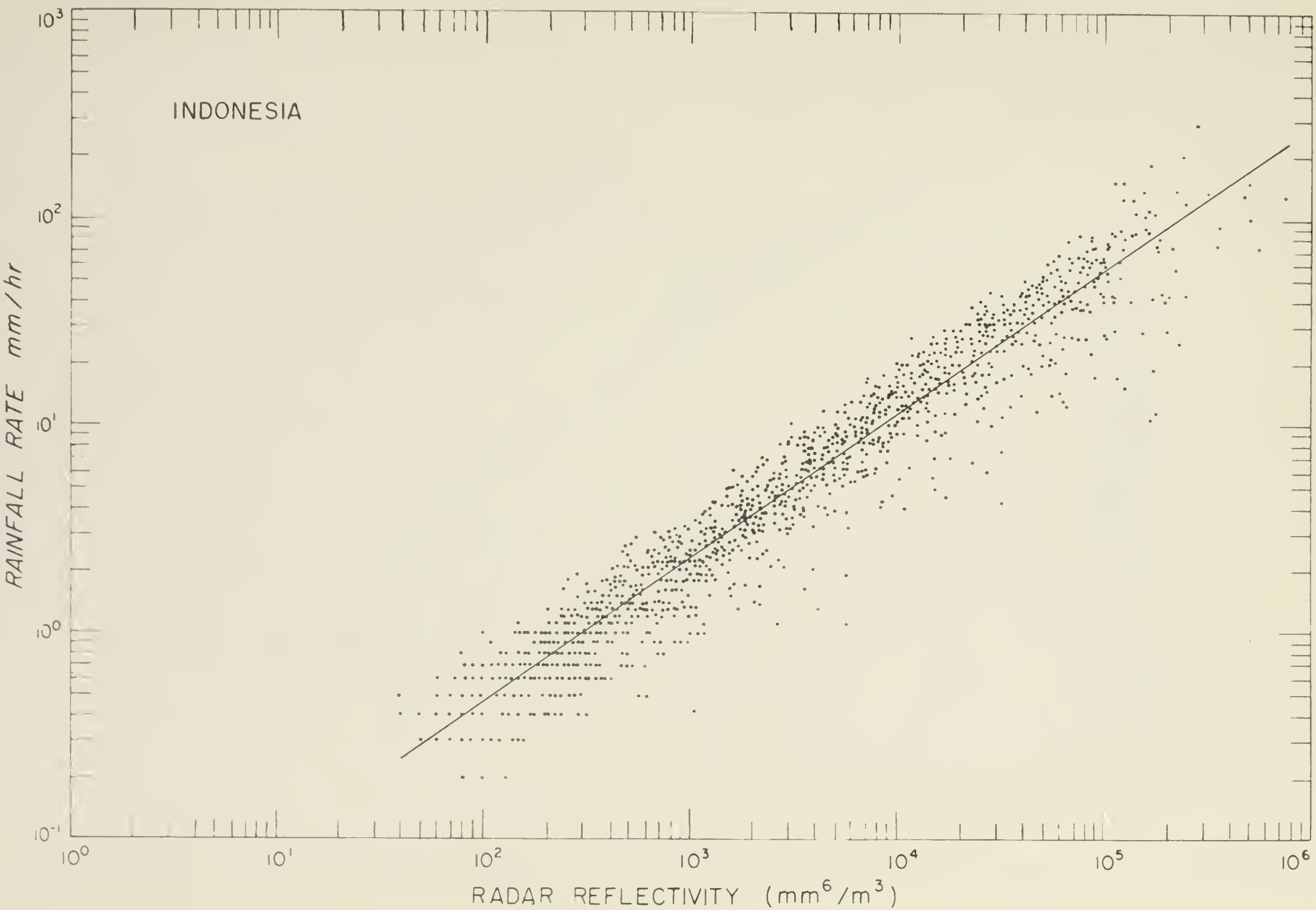

Figure 3. RAINFALL RATE – RADAR REFLECTIVITY SCATTERGRAM FOR INDONESIA DATA

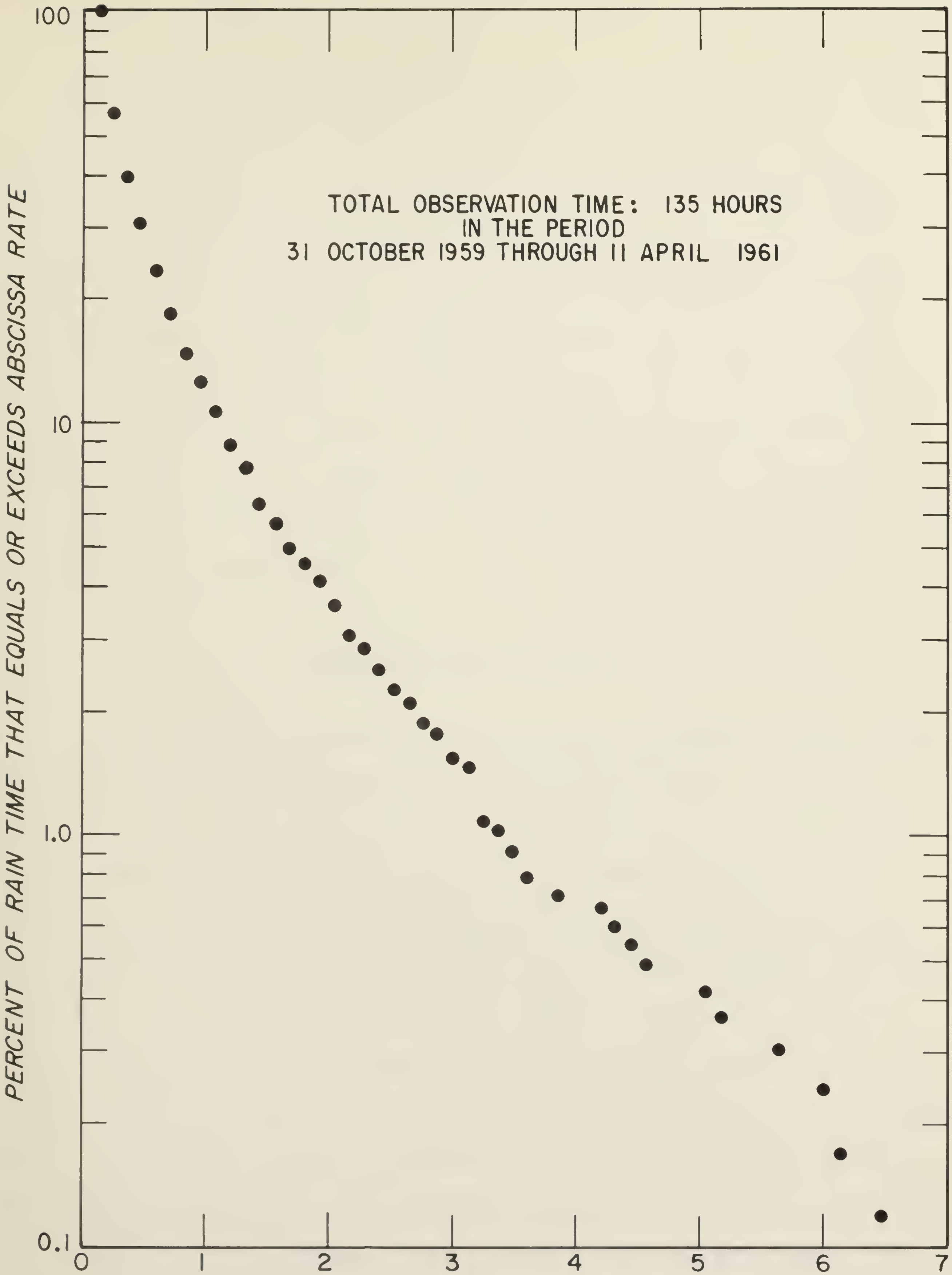

Figure 4. Frequency of Rainfall Rates Based on 5-minute Amounts from Bogor, Indonesia

Synoptic types have been determined for these stations. Also, instability indices have been calculated from radiosonde observations taken in the vicinity of the cameras. This required reprogramming of the computer program, since the program previously used was for a computer not now available. The New York City soundings have been used in conjunction with the New Jersey data. Both Greensboro, North Carolina and Athens, Georgia soundings have been analyzed for use with the North Carolina data. The stability indices and the synoptic types will be added to the drop data cards. Separation of the data by these parameters will be performed and reflectivity-rate relationships determined.

DROP-SIZE DATA REPORTS

Preparations of bound publications which summarize the raindrop distributions for all locations sampled are underway. Research Report No. 9B, dated June 1962, is an example of the type of data to be presented, this report being for the Miami, Florida data. Since at some of the locations, particularly North Carolina, much more data was obtained than at Miami, other report formats are being examined. If the approximately 4800 samples from North Carolina were to be printed as in Report 9B, a report measuring 8½ by 14 inches, and 1.4 inches thick would be required, a report of some 535 pages. Therefore, it is proposed that the data be printed out in such a format that the output, after being reduced about ½, will fit on an 8½ x 11 inch page. Such a format would require only 150 pages for North Carolina, so that the report would have a thickness

of only 3/8 in., about half the thickness of Report 9B. The other locations would require proportionately thinner reports, as the numbers of samples are less.

A computer program has been written for printing out this data. By using the computers, rather than the tabulating machine used on Report 9B, it has been possible to use a format for the summary and distribution data in which many of the parameters are labeled, making it easier to locate desired items of information. A preliminary sample of the printed output is shown in Figure 5. In this example the date and time are easily identifiable. Synoptic type will remain as coded numbers but the second column after time, rain type, will be changed to either R, RW, or TRW. The radar reflectivity, rainfall rate, radar attenuation, liquid water content, median volume diameter, and total concentration are each identified by the letters Z, R, Q, L, DL, and NT, respectively. The numbers of drops follow in 0.1 mm intervals. The second and third lines will be printed only if there is one or more non-zero entries. It is felt that the newer format will be easier to use as well as considerably less expensive than the method used in Report 9B.

INTERMEDIATE RANGE RAINGAGE NETWORK

The 15 raingages to be furnished under this contract have been received. Mounting bases for these gages are being fabricated. Site selection and installation of gages will be done in April.

```
 6JUN59 1630  70  4  R= 65.4  Z=5.55E C4  C= 315  L= 3.18  DL=1.9  NT=1755    53  84 156 187 195 187 126 112  88  72
      64  45  63  52  65  46  42 17 26 16 14  8 12  9  5  4  3  1  C  2  1  0  0  C 0 0 0 0 0 0 0 0 0 C 0 C 0 C 0 C
 8JUN59 1136  40  9  R= 76.3  Z=6.11E C4  C= 340  L= 2.61  DL=2.C  NT=1494     9  44  87 14C  98 164  65  9C  82  65
      67  71  51  76  70  71  61 43 35 23 18 12 10 11  6  3  0  2  C  C  0  C  0  0 0 0 C 0 0 0 0 C C C 0 C 0 C C C
20JUN59 1040  70  4  R= 61.1  Z=9.83E C4  C= 526  L= 3.62  DL=2.3  NT=1778    72 138 201 286 181 207  98  77  46  39
      36  25  28  31  28  41  36 31 26 30 31 20 14 17 12  8  6  2  3  2  2  C  1  2 C 0 0 1 0 0 0 0 0 0 C 0 C C C 0 0
20JUN59 1046  7C  4  R= 70.8  Z=4.70E C4  C= 263  L= 3.55  DL=1.8  NT=1714     0  11  44 124 143 232 142 126 113 113
      93 100  89  75  77  7C  59 37 11 22 12  8  5  2  3  1  C  1  1  0  0  C  0  C C 0 C 0 0 0 C 0 C 0 C 0 C 0 C C C
22JUN59 1C40  40  5  R= 72.0  Z=5.46E C4  C= 306  L= 3.50  DL=1.9  NT=1566     0  11  24 105 136 240 155 102  76  88
     112  74  66  69  68  56  45 37 23 23 18 1C 10  8  6  1  1  2  C  0  0  C  0  C 0 0 0 0 0 C 0 0 C 0 C 0 C 0 C 0 C
27JUN59 1018  40  5  R= 61.7  Z=3.47E 04  C= 194  L= 3.21  DL=1.7  NT=1552     2   6  19  72  46 105 187 17C 152 151
     119  85 1C2 102  70  62  42 23 16  8  9  1  2  C  C  0  0  C  C  0  1  0  0  C C 0 C 0 0 0 0 0 0 0 0 C 0 C 0 C C C
 3JUL59 0930  50  4  R= 81.4  Z=9.43E 04  C= 490  L= 3.82  DL=2.1  NT=1980    38  62 125 175 204 233 211 219 155 103
      71  55  36  38  25  31  27 3C 34 17 12 20 14 13  7  4  3  4  1  4  3  2  2  0 0 1 C 0 0 1 0 0 0 C C 0 C 0 C 0 C
 3JUL59 0931  50  4  R= 80.1  Z=6.15E 04  C= 348  L= 4.C2  DL=1.8  NT=2199    4C  89 1C2 189 149 232 234 207 169 142
     117  75  72  80  58  55  51 52 26 19  5  9  8  2  5  2  2  1  4  1  1  1  0  0 0 0 0 0 0 0 0 C 0 0 0 C 0 C C C
 3JUL59 0932  50  4  R= 95.2  Z=1.04E 05  C= 591  L= 4.19  DL=2.2  NT=1340    24  32  46  65  90 137 111  91  72  72
      50  44  60  67  47  56  47 40 28 30 19 23 26 21 11  8 10  4  5  1  2  C  1  0 0 0 C 0 0 0 0 0 C C C 0 C 0 C C C
 4JUL59 1347  40  4  R= 87.6  Z=1.01E 05  C= 544  L= 3.91  DL=2.2  NT=1454    16  54  84 125 111 135 108 101  81  77
      64  66  49  46  5C  40  46 28 37 32 29 12 13 11  7  9  5  4  4  3  0  3  2  0 1 1 0 0 0 0 0 0 0 0 0 C 0 C C C
25JUL59 1243  50  4  R= 90.6  Z=1.36E C5  C= 568  L= 4.07  DL=2.2  NT=16C4    43  76 111 127 120 149 104  91  82  89
      85  60  75  56  55  39  39 33 37 27 28 18 15  9 15  3  6  2  3  1  2  2  1  0 0 0 C 0 0 0 0 0 C C C 0 C 0 C C C
  0 C 0 C 1 0 0 0 C C C 0 C C 0 C 0 0 C C 0 C C C
18AUG59 1240  40  9  R= 75.0  Z=6.12E C4  C= 349  L= 3.67  DL=1.9  NT=1825     C   0  18  91 203 395 228 157 104  9C
      74  56  58  61  60  44  38 22 28 23 17 17 17  9  7  3  2  1  1  1  0  C  0  0 0 0 C 0 0 0 0 0 0 C 0 C 0 C 0 C
21AUG59 1945  40  5  R= 65.4  Z=3.57E 04  C= 197  L= 3.30  DL=1.8  NT=1217     0   0   0   0   6  46  52  62  97 116
     123 153 137 168  98  75  32 24 11 10  4  2  1  C  C  C  0  0  C  0  0  0  0  C 0 0 0 0 0 0 0 0 0 C 0 C 0 C C C
22AUG59 1C14  50  7  R= 80.2  Z=7.06E C4  C= 384  L= 3.83  DL=2.0  NT=1762     6  30  74 171 129 263 158 12C  93  66
     109  87  75  82  42  43  48 39 26 26 24 13  8 14  5  4  2  2  0  0  1  C  1  0 0 1 C 0 0 0 C 0 C C C 0 C 0 C 0 C
22AUG59 1C16  50  4  R= 73.7  Z=6.51E 04  C= 294  L= 4.C1  DL=1.6  NT=3913   104 274 643 700 612 386 304 179 124  95
      85  61  53  41  34  45  46 35 31 15 15 11  7  5  1  2  3  0  C  1  0  0  0  C 0 0 0 0 0 0 0 0 0 0 0 1 0 C 0 C
22AUG59 1017  50  4  R= 69.2  Z=6.46E 04  C= 353  L= 3.53  DL=1.8  NT=2522    10  55 189 437 420 288 293 146 134  91
      84  64  54  48  37  42  24 25  9 10 12  9  8  8  4  7  5  3  1  0  1  1  2  0 0 0 1 0 0 0 0 0 C 0 C 0 C 0 C C C
23AUG59 1532  50  4  R=135.0  Z=1.31E C5  C= 711  L= 6.C4  DL=2.1  NT=1654     C   0   0   4  13 130 150 121 118  86
     101  98 1C4 138  80 119  92  2 81 69 45 28 27 15  7 11  6  2  2  2  1  1  0  0 0 0 C 1 0 0 0 0 0 0 0 0 C 0 C 0 0
23AUG59 1533  50  4  R=1C2.3  Z=9.47E 04  C= 520  L= 4.56  DL=2.2  NT=1151     0   0   C   1   3  53  69  73  82  73
      61  75  80 106  52  98  62 65 47 39 37 18 26 15  3  2  5  2  2  1  0  C  1  C C C C 0 0 0 0 0 C 0 C 0 C 0 C C C
23AUG59 1534  50  4  R=137.4  Z=1.33E C5  C= 741  L= 6.C8  DL=2.2  NT=1517     C   0   0   0   1  48  82 117 12C  92
      88 135 120 130  76  85  89 54 49 74 29 34 34 2C 16  9  8  2  2  2  0  C  1  0 0 0 0 0 0 0 0 0 0 C 0 C 0 C 0 C
23AUG59 1535  50  4  R=134.8  Z=1.32E 05  C= 746  L= 6.C6  DL=2.1  NT=1689     1   0   C   2   6  50 118 148 153 144
     135 139 138 119  89  89  69 57 49 34 27 32 24 16 18  6  5 12  5  1  1  2  0  0 0 0 0 0 0 0 0 0 0 0 0 C 0 C C C
23AUG59 1536  50  4  R=170.7  Z=1.86E 05  C=1C1C  L= 7.52  DL=2.2  NT=2021     C   0   1   4   4 140 181 197 146 142
     115 144 157 132  91  91  78 69 52 54 49 42 39 3C 21  8 11  6  6  1  2  3  2  1 1 0 C 1 0 0 0 0 C 0 C 0 C C C 0 C
23AUG59 1710  50  4  R= 71.1  Z=7.11E 04  C= 387  L= 3.34  DL=2.0  NT=1531    34 172 126  63  74 101 1C1 104 107 1C2
      71  77  79  67  42  48  25 34 21 22 14 14  6  4  2  5  3  1  3  2  2  2  3  0 0 0 0 0 C 0 0 0 0 0 0 0 C 0 C 0 C
23AUG59 1711  50  4  R= 82.0  Z=6.40E C4  C= 35C  L= 3.80  DL=2.C  NT=1108     C   0   0   2   2  50  59  84  76  96
      82  92  82 127  42  69  54 46 38 39 21 19 17  9  1  1  0  0  0  0  0  0  0  0 0 0 C 0 0 0 0 0 C 0 C 0 C 0 C 0 C
 1SEP59 1533  50  4  R= 62.4  Z=8.04E C4  C= 426  L= 2.64  DL=2.3  NT= 588     C   C   1   8   8  39  36  3C  3C  42
      34  32  33  45  35  37  36 27 16 18 14 12  5 13 12  5  5  4  3  2  1  2  1  1 0 0 0 1 0 0 0 0 0 0 C 0 C 0 C C C
 1SEP59 1534  50  4  R= 88.7  Z=1.65E 05  C= 59C  L= 3.80  DL=2.2  NT= 888     0   0   C   1   0  33  28  56  64  78
      76  83  54  87  51  53  55 31 31 20 16 10 14  8 1C  8  3  5  2  2  1  3  1  0 0 0 1 0 0 0 1 0 C 0 C 0 C 1 C C C
  C C 0 C 1 0 C 0 0 C 0 0 C C 0 0 C C C C 0 0 C C
 1SEP59 1535  50  4  R=151.3  Z=4.23E 05  C=1341  L= 6.16  DL=2.9  NT=2031     C   0  13  8C 212 390 308 217 163 124
      87  77  44  36  27  31  15 11 21 20 1C 11 11 10 12 10  9  4  8  9  7  8  8  8 6 4 2 3 2 2 1 1 0 2 2 1 C 0 1 1 C
  1 C 0 C 0 0 0 C C C C 0 C C C 0 0 C C C C 0 C C C
 1SEP59 1555  50  4  R= 73.8  Z=7.76E C4  C= 404  L= 3.51  DL=2.0  NT=19C0    26 133 183 215 176 211 148  97  83  99
      80  62  75  57  48  46  3C 16 23 19 14 14  9 1C  6  6  3  2  1  3  1  1  0  0 1 1 C 1 0 0 0 0 0 0 C 0 C 0 0 0 C
 1SEP59 1556  50  4  R= 69.7  Z=6.50E 04  C= 370  L= 4.67  DL=1.8  NT=3488     7  80 413 622 533 464 256 17C 13C 115
     108  94  90  72  73  67  46 36 28 15 22 16 1C  8  6  2  0  2  1  1  0  1  0  C C 0 C 0 0 0 0 C 0 C 0 C 0 C C C
 1SEP59 1557  50  4  R= 68.4  Z=4.54E C4  C= 253  L= 3.49  DL=1.8  NT=2122   152 183 138 138 137 226 166 124 132 1C2
      98  82  79  65  79  58  54 38 23 21 12  5  2  3  1  2  1  0  0  0  0  1  0  0 C 0 0 0 0 0 0 0 0 0 C 0 C 0 C C C
 1SEP59 1604  50  4  R= 87.2  Z=7.17E 04  C= 398  L= 4.19  DL=1.9  NT=17C4     C   8  28  75 113 191 143 124 134 153
     121  93  83  79  76  60  57 50 26 25 23 11  8  6  4  4  2  1  2  1  2  0  1  0 0 0 0 0 0 0 0 0 0 0 0 C 0 C C C
 1SEP59 1605  50  4  R= 87.6  Z=8.03E 04  C= 452  L= 4.12  DL=2.0  NT=1714     2   9  37 136 196 241 146  98 100  8C
      92  76  66  8C  88  68  32 33 36 31 14 14  6 11 12  9  3  2  3  1  0  1  1  0 0 0 C 0 0 0 0 0 C C C 0 C 0 C 0 C
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Figure 5. Sample Page from Planned Raindrop Data Reports

The network is to be established in an area approximately 75 miles from the radar, near Kankakee, Illinois, and will be known as the Kankakee Raingage Network. Other networks are already in operation at 25 to 35 miles and at approximately 150 miles. With the addition of this new network, areal radar and rainfall measurements can be obtained from three ranges, making it possible to determine the accuracy of radar-rainfall measurements as a function of range.

CONCLUSIONS AND RECOMMENDATIONS

The volume sample size study has been completed. The results of this study indicate that the one-cubic-meter volume of sample used in past data collections is adequate for proper determination of the rainfall rate-radar reflectivity relationship. Only about 10 percent of the variance in the relationship can be properly attributed to the size of the volume sampled. The study also indicates that a relatively large volume of natural rainfall must be sampled to reliably estimate the value of rainfall rate or reflectivity from a drop size spectrum. The natural variability of raindrops requires samples on the order of 50 m^3 to estimate the parameters to within 10 percent of the mean 95 percent of the time.

The Indonesia data has been examined and a reflectivity-rate relationship determined. Of the areas sampled with a drop camera climatic conditions in Indonesia most nearly approximate the climate of South Viet Nam; this relationship is recommended for any radar weather work performed in that area. An analysis of frequency of

rainfall rates from the raingage was performed. This data provides some estimate of the importance of rain attenuation under these climatic conditions.

The dropsize data from New Jersey and North Carolina have been edited and typed with respect to thermodynamic instability and synoptic types. This completes the typing for all drop size data that can be typed.

A format for the data printouts has been designed and it is recommended for use in the data printouts which will be performed.

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13 ABSTRACT

The results of the drop size sample study indicate that volumes of about $50 m^3$ are necessary to estimate rainfall rate and radar reflectivity to 10 percent accuracy with 95 percent confidence. One-cubic-meter samples are sufficiently large that rainfall rate-radar reflectivity relationships can be reliably determined. The sample size variances contribute about 10 percent of the logarithmic scatter around the regression line.

Analysis of drop size data from Indonesia yielded a reflectivity rate relationship similar to that from Miami, Florida data but with less scatter. Five-minute rainfall rate frequencies from Indonesia were also similar to those from Florida.

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